SHORT COMMUNICATION

Optical Filter Effects on Night Vision Goggle Acuity and Preservation of Dark Adaptation

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Introduction: The high output of night vision goggles (NVGs) can cause a loss of dark adaptation, resulting in suboptimal unaided vision. Optical filters have been designed to mitigate this problem by changing the overall output characteristics of the NVGs. ***Methods:*** Several aspects of visual performance related to NVG use were studied in a repeated measures design, filters versus no filters. NVG acuity was assessed using a 25% contrast chart, while preservation of dark adaptation after NVG use was measured with a scotopic sensitivity tester (SST) and a low luminance acuity chart. Testing was accomplished at two light levels, roughly corresponding to starlight and quarter moon conditions. ***Results:*** Use of the filters resulted in a statistically significant loss of acuity of about a 1/2 line (approximately 2.5 letters) at both light levels. The second part of the study identified a 47% improvement in preservation of dark adaptation under simulated starlight conditions and a 31% improvement under simulated quarter moon conditions with filter use; however, only the starlight finding was statistically significant. No significant differences in performance were seen with the low luminance chart. ***Discussion:*** Despite a small loss of visual acuity with filter use, the improvement in retention of dark adaptation may be beneficial in certain operational environments. Aviators, airmen, and commanders should evaluate how the potential for slightly poorer visual acuity and improved recovery of dark adapted vision relates to their mission specific requirements prior to implementing use of NVG filters.

Keywords: optical filters, scotopic sensitivity tester, F4949, AN/AVS-9, dark adaptation, night vision, night vision goggles.

NIGHT MILITARY operations often involve performing demanding visual tasks under conditions of very low luminance. The human eye is able to adapt to light levels over many orders of magnitude, but at extremely low levels, light amplifying devices such as night vision goggles (NVGs) are beneficial in maintaining usable vision. They provide a luminous gain of about 5500x, with a maximum eyepiece output of approximately 17 $cd \cdot m^{-2}$ (5). NVGs provide a powerful tactical advantage; however, exposure to NVG output can disrupt the dark-adapted state of the human retina. This process of light adaptation occurs rapidly and leads to decreased unaided retinal sensitivity of dimly lit objects relative to pre-exposure levels. Removal of the NVGs will slowly return unaided vision to a dark-adapted state.

The temporary loss of retinal sensitivity following NVG use could be a potential risk for aircrew operating in the high-speed environment of military aviation or for any soldier who needs to make immediate decisions based on visual information acquired after NVG use. A previous study demonstrated a delay of several seconds in identifying dimly lit cockpit instruments after viewing through NVGs, an effect that was more pronounced with older subjects (1). A second study found that peripheral retinal sensitivity outside the NVG field of view is decreased during NVG use (4). To mitigate these risks, filters have been developed to be worn over the eyepiece of the NVGs and are designed to attenuate the output of the goggles and improve retention of dark adaptation. These filters selectively absorb light on the short wavelength end of the visible spectrum, where rod receptors are most sensitive, and transmit light on the long end of the spectrum, where cone receptors are most sensitive. This modulation of NVG output is intended to allow for good photopic vision when viewing through the NVGs, with improved retention of the dark-adapted state after NVG use. Anecdotal evidence suggests that there are visual benefits gained by wearing filters in conjunction with NVGs; however, to date no studies have formally verified these claims.

METHODS

This study had a repeated measures design with subjects serving as their own control. Three aspects of visual function related to NVG use, with and without filters, were evaluated: visual acuity through the NVGs, preservation of dark adaptation after NVG use, and low luminance target identification following NVG use. There were 15 subjects who participated in assessing NVG acuity and 7 who participated in evaluation of preservation of dark adaptation and target identification, including 3 subjects who participated in all phases of the study.

Subjects

Subjects were nonsmoking, active duty U.S. Air Force (USAF) members (mean age 33.2 yr, range 25-45) with no current or previous ocular pathology. All had

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uncorrected or best corrected Snellen visual acuities of 20/20 (6/6) or better and were evaluated with their habitual method of correction. Informed consent was obtained prior to participation, and the study protocol was approved by the Wright Patterson Air Force Base Institutional Review Board and the USAF Surgeon General's Office of Research Compliance.

Test Environment

Testing took place in a specially designed night vision lab using a single F4949G NVG (ITT, White Plains, NY), which was identical to models used operationally by many USAF aircrew, with the exception that the power supply used an A/C adapter rather than a battery. An LM-33-80A variable night sky projection system (Hoffman Engineering, Stamford, CT) provided simulated night sky light levels and chart radiance was calibrated using a PR-1530 photometer and radiometer (Photo Research, Chatsworth, CA). Two light levels were selected for study. The high light level was defined as the point at which the goggles had maximum output when exposed to a target of uniform radiance that filled the goggle field of view, determined to be 3.5×10^{-9} watts $\cdot$ cm^{-2} $\cdot$ $steradian^{-1}$. The low light level was defined as 3.0×10^{-10} watts $\cdot$ cm^{-2} $\cdot$ $steradian^{-1}$, approximately one order of magnitude less than the high level. These light levels are representative of operational environments where NVGs may be used and roughly correlate to quarter moon and starlight conditions; however, it should be noted that there are no defined standards among researchers for these conditions (3,6).

Filters

The filters used in this study were Orion night vision filters (Spectrum Technologies International Ltd., Naperville, IL), a commercially available filter designed for use with the F4949 NVG (2). When measured on a spectrophotometer, the filter transmits approximately 20% of light between 540 and 550 nm, which is the band of maximum output for the NVG (**Fig. 1**). In the laboratory, the filters reduced the overall output of the NVGs by 73%.

Procedure

NVG visual acuity was assessed using a 25% contrast ETDRS style chart (Precision Vision, La Salle, IL), which was measured at 50% Weber contrast in the night vision imaging system region (600–900 nm). This chart displays five letters per line and each succeeding line represents a change of 0.1 logMAR units. Acuity scores were based on the total number of letters correctly identified with each letter valued at 0.02 logMAR units. Testing was accomplished binocularly under simulated starlight conditions with the filters in place and repeated without the filters. The testing was repeated under simulated quarter moon conditions. Multiple letter charts with different letter sequences were used to avoid memorization.

Preservation of dark adaptation was measured using an SST-1 scotopic sensitivity tester (SST; LKC Technologies,

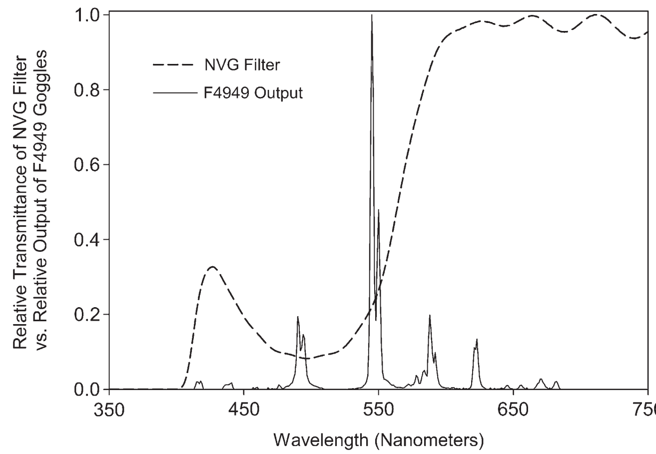

Fig. 1. The transmittance of the NVG filters in comparison with the output of the NVGs. The filter curve is graphed as the relative transmittance versus wavelength while the NVG curve is the relative output compared to maximum output versus wavelength.

Gaithersburg, MD), which has a round LED illuminated screen 40 mm in diameter with a dominant output wavelength of 572 nm. This LED was measured to produce $2.43 \cdot 10^{-3}$ cd $\cdot$ m^{-2} and can be stepped down up to 3 log units in 0.1 log unit increments. After dark adapting for 45 min, subjects viewed the LED monocularly at a distance of 14 cm (a distance required to ensure that the area of retina exposed to the LED was confined within the area exposed to the output of the NVGs). The intensity of the LED was then stepped down manually in 0.1 log unit increments until the subject was no longer able to reliably detect the light. This minimal level of detection was the baseline sensitivity. Subjects then viewed through NVGs fitted with the filters at a uniformly lit projector screen at a distance of 3 m for 2 min under simulated starlight conditions. Following the exposure, the time required to identify the LED at 0.2 log units above the baseline level was measured (testing slightly above threshold levels yielded improved reproducibility of findings). Subjects were then given a 5-min rest period and tested with the unfiltered NVGs. The entire sequence was repeated under simulated quarter moon conditions with and without the filters.

Low luminance target identification after NVG use was assessed using a high contrast, retro-illuminated ETDRS style acuity chart (Precision Vision, La Salle, IL) that was overlaid with a 3.3 log neutral density filter, resulting in a chart luminance of 2.2×10^{-2} cd $\cdot$ m^{-2}. After dark adapting for 45 min, baseline acuity was established as the maximum number of letters that could be correctly identified on the chart under binocular conditions. Subjects were then exposed to NVGs for 2 min under simulated starlight conditions with the filters in place. Following the exposure, the time required to correctly identify two letters less than the baseline level was measured. The testing sequence was then repeated without the filters followed by testing under simulated quarter moon conditions with and without filters. For each test, eye charts of different letter sequences were used to minimize subject memorization. Significant differences in performance between the no filter and filter condition for each visual task were analyzed using the related-samples Wilcoxon signed ranks test (SPSS, Chicago, IL).

RESULTS

The use of optical filters to attenuate the NVG output resulted in a relatively small but statistically significant decrement in visual acuity through the goggles under both simulated starlight and quarter moon conditions (**Table I**). This equated to a loss of approximately one-half of a line of acuity at each light level. Improved preservation of dark adaptation was observed under both lighting conditions with the use of optical filters; however, this difference was only significant at the starlight level (**Table II**). The time required for subjects to return to baseline dark-adapted levels was reduced by 66 s under starlight conditions and 144 s under quarter moon conditions with filters in place relative to viewing through the NVGs alone.

Evaluation of low luminance target identification after NVG use yielded equivocal results (Table II). Under simulated starlight conditions, optical filters reduced the time needed to return to the pre-exposure level by 24 s. However, under quarter moon conditions, the time required to return to baseline levels was 5 s shorter without filters in place. Neither of these findings were statistically significant.

DISCUSSION

This study demonstrates that optical filters worn in conjunction with NVGs are potentially beneficial in maintaining the dark-adapted state of the retina after exposure to the goggle output. Under simulated starlight conditions, the time required for subjects to recover to a baseline (i.e., pre-NVG use) level of dark sensitivity was reduced by nearly 50% by using filters. At simulated quarter moon conditions, the recovery time was reduced by 30%, although this was not a statistically significant finding. Using the filters comes at the cost of decreased acuity through the goggles. For each lighting condition, subjects lost approximately one-half of a line of acuity when viewing through filters, a relatively small but significant difference.

The use of filters over the goggles did not have any measureable impact on the delay in identifying dimly illuminated targets after NVG use. Several explanations may account for this finding. The low luminance chart employed in this study used cone dependent central visual acuity. Cone pigments regenerate much more quickly than rod pigments, making it more difficult to accurately measure the rate of recovery and identify significant differences. Furthermore, NVG filters are designed to allow for good photopic (i.e., cone based) vision, so preservation of cone-based vision following NVG use would not be expected.

TABLE I. NIGHT VISION GOGGLE VISUAL ACUITY ($\bar{x}$ ± SD).

Condition	Without Filters	With Filters
Starlight	0.45 ± 0.07 (20/57)	0.50 ± 0.07* (20/63)
1/4 Moon	0.28 ± 0.06 (20/38)	0.33 ± 0.07* (20/43)

Visual acuities are reported in LogMAR units with the Snellen equivalent of the mean in parenthesis.
* Indicates a significant difference ($P < 0.05$).

TABLE II. TIME REQUIRED TO ACHIEVE BASELINE PERFORMANCE AFTER EXPOSURE TO NIGHT VISION GOGGLES ($\bar{x}$ ± SD).

Task	Condition	Without Filters	With Filters
Dark Adaptation	Starlight	141 ± 34	75 ± 31*
	1/4 Moon	472 ± 208	328 ± 228
Low Luminance Target Identification	Starlight	67 ± 64	43 ± 23
	1/4 Moon	98 ± 75	103 ± 78

Findings are reported in units of seconds.
* Indicates a significant difference ($P < 0.05$).

The primary consideration in using the filters is whether the benefit of potentially decreased dark adaptation recovery time outweighs the risk of reduced visual acuity. This study was able to quantify the decrease in visual acuity, but found a statistically significant difference in recovery times under only one light level. It was conducted in the controlled environment of a laboratory and cannot necessarily be directly correlated with operational use. It is important, however, that aviators and other airmen recognize the potential effects when using NVG filters. The findings do not eliminate the possibility that the filters could produce a statistically significant benefit under multiple light levels in a larger study or provide a subjective benefit under operational conditions. From the results, there is no indication that the filters should be restricted from use, but operators should be aware of performance limitations. Airmen assigned to night scanning duties who require maximum visual acuity may elect to not use filters while ground forces who only intermittently use NVGs for scanning may elect to use filters. Aviators, airmen, and commanders should evaluate how the potential for slightly poorer visual acuity and improved recovery of dark-adapted vision relates to their mission-specific requirements prior to implementing use of NVG filters.

Finally, the goal of this research was to evaluate NVG filters that are currently available and being used operationally. Alternative filter designs, such as neutral density filters, may provide similar behavior under laboratory and operational conditions. However, no commercial NVG neutral density filters were known to be available during this study and perhaps this question may be addressed in future work.

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REFERENCES

1. Howard CM, Riegler JT, Martin JJ. Light adaptation: night vision goggle effect on cockpit instrument reading time. Aviat Space Environ Med 2001; 72:529–33.
2. Kovener GS. Spectrum technologies international orion night vision filters, delta thermal imaging filters and spectrum optical eyeware. 2005; retrieved 15 May 2008 from: http://www.spectrumfilters.com/emails/whitepaper/whitepaper1.pdf.
3. Marasco PL, Task HL. The impact of target luminance and radiance on night-vision device visual performance testing. Proc Soc Photo Opt Instrum Eng 2003; 5079:174–83.
4. McLean WE. Peripheral vision sensitivity with night vision devices. U.S. Army Aeromedical Research Laboratory. 1998; report Number 98-19. Retrieved 23 February 2010 from: http://www.usaarl.army.mil/TechReports/98-19.PDF.
5. Night Vision Goggles/Image Intensifier Set AN/AVS-9 (F4949 Series). 2007; retrieved 14 March 2009 from: http://www.nightvision.com/products/military/product_pages/datasheet/anavs-9_f4949_series.pdf.
6. Radio Corporation of America. Electro-optics handbook. Harrison, NJ: Radio Corporation of America; 1974:61–79.